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WASTE DISPOSAL FOR AEROSPACE MISSIONS

TECHNICAL DOCUMENTARY REPORT NO. AMRL-TDR-63-4

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Life Support Systems Laboratory
6570th Aerospace Medical Research Laboratories
Aerospace Medical Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Contract Monitor: A. B. Hearld
Project No. 6373, Task No. 637305

[Prepared under Contract No. AF 33(616)-8203
by
P. P. Nuccio
C. M. Tomsic
J. D. Zeff
MRD Division, General American
Transportation Corp., 7501 N. Natchez Ave.
Niles 48, Illinois]

NOTICES

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Aerospace Medical Division
6570th Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio
Rpt. No. AMRL-TDR-63-4. WASTE DISPOSAL FOR AEROSPACE MISSIONS. Final rpt. Jan 63, vi + 47 pp, incl. illus., tables, 8 refs. Unclassified report

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1. Sanitation
2. Space Vehicles
3. Disposal (Sanitary Engineering)
4. Incinerators (Sanitary Engineering)

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is 700° F. (c) Incineration using pure oxygen at 160 mm Hg absolute generates 100 watts after ignition has been attained. (d) Thermal decomposition of the wastes requires a continuous input of 390 watts for 12 hours. Based upon the power requirements and a mass penalty of 0.15 pound/watt, incineration with pure oxygen was found to be best waste-disposal technique for a 3-man, 14-day mission. In the second phase, the laboratory model was designed, fabricated, and tested. The complete system weighed 81 lbs and occupied 3.1 cubic feet. It was determined experimentally that a complete incineration cycle requires 2.6 kw-hr of electrical energy and 1/2 lb of oxygen, over a 12-hour period.

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FOREWORD

This report was prepared by the MRD Division of the General American Transportation Corporation, Niles, Illinois, to summarize the work performed under Contract AF 33(616)-8203 for the investigation of incineration to dispose of wastes during aerospace missions. The work was monitored by Mr. A. B. Hearld, Accommodations Section, Sustenance Branch, Life Support Systems Laboratory, under Project 6373, "Equipment for Life Support in Aerospace," Task 637305, "Life Support Accommodations, Integration, and Analysis."

The work reported herein was initiated by the MRD Division while under ownership of the American Machine & Foundry Company. On 1 September 1962 this Division was purchased by the General American Transportation Corporation as a going operation. All customer contracts, including AF 33(616)-8203, were included in the sale. The research sponsored by this contract was started in March 1961 and was completed in August 1962.

The authors sincerely appreciate the assistance of Messrs. H. F. Behls, H. M. Sitko, and R. W. Bickes of the MRD Division in performing this work.

This report is cataloged by the MRD Division as GATC Report MRD 1161-51.

ABSTRACT

This report summarizes a program to develop a 3-man, laboratory-model, waste-disposal system for a 14-day aerospace mission. The program was divided into 2 phases. First, an experimental phase was undertaken to determine the thermal properties of the wastes using an experimental disposal system. The experimental phase determined that:

a) The specific heat of the wastes involved is 0.625 Btu/°F-lb.

b) The ignition temperature of the wastes is 700°F.

c) Incineration using pure oxygen at 160 mm Hg absolute generates 100 watts after ignition has been attained.

d) Thermal decomposition of the wastes requires a continuous input of 390 watts for 12 hours.

Based upon the power requirements and a mass penalty of 0.15 pound/watt, incineration with pure oxygen was found to be the best waste-disposal technique for a 3-man, 14-day mission. In the second phase, the laboratory model was designed, fabricated, and tested. The complete system weighed 81 lbs and occupied 3.1 cubic feet. It was determined experimentally that a complete incineration cycle requires 2.6 kw-hr of electrical energy and 1/2 lb of oxygen, over a 12-hour period.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

Wayne H. McCandless

WAYNE H. McCANDLESS
Chief, Life Support
Systems Laboratory

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SECTION 1

INTRODUCTION AND SUMMARY

Background

Methods for storing and disposing of human wastes during aerospace missions were previously studied by MRD. It was concluded that no single technique would be suitable for all types of missions. The human wastes generated are best stored at temperatures above 120°C, at temperatures below 0°C, or in a liquid disinfectant. For this program, MRD designed, fabricated, and evaluated a laboratory model of a waste storage unit that freezes the wastes by evaporation and sublimation of urine and fecal water. This is considered to be the best technique for missions without a water reclamation system.

For long-duration missions it is desirable to dispose of human wastes. The previous study concluded that disposal of these wastes can be satisfactorily accomplished by incineration and/or decomposition. It was recommended that these techniques be studied in more detail.

Program Objectives

This research program required an investigation of incineration to dispose of wastes during aerospace missions. A preliminary design study and the evaluation of a laboratory model incinerator were required.

The model was to be designed to withstand conditions of aerospace flight, be of minimum weight and volume, and require minimum power. The wastes to be disposed included human feces, and burnables such as garbage, toilet paper, sponges, unused liquid foods, and polyethylene tubes. The disposal of urine was not required. The model was to be designed to use minimum cabin atmosphere and to allow the disposal of any remaining residue overboard.

Results

The laboratory model was designed and fabricated to conform with the foregoing objectives. The completed model is shown in Figure 14. The design of the model was based on experimental information obtained in the preliminary study phase of the program.

The test of the laboratory model determined the following important performance characteristics.

1. Pure oxygen is required for incineration and 0.5 pound was required for wastes accumulated in a 24-hour period.

2. The ash remaining after incineration was dry, powdery, and can be blown overboard or to storage in sufficient quantity to prevent accumulation* over extended periods of time. The average amount of ash remaining from each incineration is approximately 20 gm.

* in the incinerator

3. The use of solar radiation as a partial replacement of input electrical energy was not demonstrated, because of the unavailability of a 3-foot diameter lens, which is the minimum size required to concentrate the energy available from the MRD solar simulator.

4. The temperature of successful incineration was determined to be 1000°F.

5. The total energy required to incinerate a 3-man-day load of waste in a 12-hour period was less than 4 kilowatt-hours.

Recommendations

From the design and test information obtained in developing the laboratory model two alternative means of developing flight-prototype waste disposal systems became evident.

1. Perform an advanced design analysis on the present model to decrease power consumption, weight, volume, and oxygen demand, and improve the solar energy utilization. This analysis would consider grinding or pulverizing of the waste prior to incineration, use custom installed insulation, and reduce the ratio of chamber surface area to storage volume.

2. Develop a system that does not require oxygen but relies solely upon vacuum vaporization and/or decomposition. The wastes would require grinding or pulverizing prior to being passed into the heating chamber for vaporization and exposure to external vacuum.

SECTION 2

PRELIMINARY DESIGN STUDY

This program was initiated by the preliminary design study to determine the optimum design for a waste incinerator capable of disposing of the daily wastes from 3 men on a 14-day aerospace mission. The analytical, experimental, and preliminary design work performed is as follows.

Waste Parameters

Quantity and Composition of Wastes

In previous work on waste storage and/or disposal (Ref. 1), MRD estimated the quantity and type of wastes for aerospace missions. It was found that the character and the quantity of wastes can be classified according to the type of life-support system provided with the vehicle, as shown in Table 1. For a 3-man, 14-day mission it is assumed that a closed water cycle will be utilized. Table 1 indicates that the quantity of nongaseous wastes generated on such a mission would be a maximum of 750 grams per man-day. This table did not account for (1) plastic bags from a compression distillation water recovery system, (2) paper, and (3) food residue. In Table 2 the average estimated quantity of wastes is 535 grams which accounts for this omission.

The exact chemical composition of the wastes cannot be predicted, since the composition will depend upon the diet of the crew, the design of the vehicle, and the design of the life-support systems. Table 2 presents the estimated chemical analysis of wastes that will probably be generated on the specified mission. It was assumed that no metallic wastes will be involved and that the plastics used can include cellulose acetate, polyvinyl chloride, acrylic resins and polyethylene. These plastics have all been used in the fabrication of disposable items designed to be used in aerospace vehicles (Ref. 2).

Oxygen Usage

Decomposition of wastes is defined as the thermal break-down of wastes to gaseous products, without the use of oxygen. Incineration is defined as the complete oxidation of wastes by the use of oxygen in either pure form or diluted with an inert gas such as nitrogen. The amount of oxygen consumed in incineration can be predicted providing the chemical composition of the wastes are known. Using the wastes described in Table 2, the oxygen required to incinerate the daily wastes of 3 men should be as follows.

Separated Wastes	Type of Life-Support System			
	Open Cycle	Closed Water Cycle	Closed Water-Oxygen Cycle	Completely Closed Cycle
Refuse				
Filters	100	100	100	---
Sponges	0- 50	75	50	---
Food Tubes	50	50	50	---
Cartridges	0	25	25	---
Paper	---	---	---	---
Bladders	0	0	25	---
Gases				
Odors	0	---	---	---
Cabin Gas	0	20-100	20-100	---
Water Vapor	0	0-200	0-200	---
Carbon Dioxide	0	1170	0	---
Packages Feces				
Feces	150	150	150	0
Bags and Paper	50	50	50	0
Urine	1400	0	0	0
Wash Water	0-1000	0	0	0
Total	1750-2800 gm	1640-1920 gm	470-750 gm	0-450 gm

TABLE 1 TYPE AND MASS OF WASTES SEPARATED FROM CABIN EACH MAN-DAY

Refuse	Total Mass gm	Free H_2O Content gm	Dry Mass gm	C gm	H gm	O gm	N gm	S gm	Cl gm	Ash gm
Sponges[1]	75	0	75	37.5	4.2	33.3				
Food Tubes[2]	50	0	50	43.0	7.0					
Cartridges[3]	25	0	25	14.1	1.5	9.4				
Paper[4]	25	0	25	11.1	1.6	12.3				
Plastic Bags[2]	10	0	10	8.6	1.4					
Filters[5]	100	0	100	38.7	4.8				56.5	
Packaged Feces										
Feces[6]	150	100	50	17.1	2.6	2.4	10.3			17.6
Bags and Paper[4]	50	0	50	22.2	3.2	24.6				
Garbage										
Edible Residues[7]	50	37.5	12.5	5.6	0.8	3.1	0.4	0.1		2.5
TOTALS	535	137.5	397.5	197.9	26.9	85.1	10.7	0.1	56.5	20.1

1. Assume Cellulose Acetate $(C_{12}H_{16}O_8)_x$
2. Assume Polyethylene $(C_2H_4)_x$
3. Acrylic Resins $(C_4H_5O_2)_x$
4. Assume Cellulose $(C_6H_{10}O_5)_x$
5. Assume Polyvinyl Chloride $(C_2H_3Cl)_x$
6. See Reference 8
7. See Reference 4

TABLE 2
ESTIMATED ANALYSIS OF WASTES
ONE MAN-DAY BASIS

Component & Quantity	Assumed Reaction	O_2 Required
C, 593.7 gm/day	$C + O_2 \rightarrow CO_2$	1583.2 gm/day
H, 80.7 gm/day	$2H_2 + O_2 \rightarrow 2H_2O$	645.6 gm/day
S, 0.3 gm/day	$S + O_2 \rightarrow SO_2$	0.3 gm/day
Sub-total		2229.1 gm/day
Less Combined O_2 (3 x 85.1)		255.3
Theoretical O_2 requirement		1973.8 gm/day

If the combustion is not complete, CO will form instead of CO_2 and less O_2 will be required. It is also likely that an excess amount of oxygen may be required to obtain complete combustion. The design of the incinerator, therefore, will strongly influence the actual oxygen requirement.

Energy Considerations

In either decomposition or incineration the wastes would be collected and confined within a thermally insulated chamber and heat applied until a sterilizing temperature of 250°F and a pressure of 29.8 psia is attained. When the contents are sterile, the gases and vapors could be vented overboard and heating continued for drying the wastes and for eventual ignition (incineration) or decomposition. Thermoplastics, of course, would melt prior to vaporization and/or ignition.

Incineration - The energy balance involved in incinerating wastes under the specified conditions can be expressed as follows:

$$\Sigma Q_{\text{input}} + \Sigma Q_{\substack{\text{net heats}\\ \text{of combustion}}} = \Sigma Q_{\substack{\text{sensible}\\ \text{wastes}}} + \Sigma Q_{\substack{\text{sensible}\\ \text{system}}}$$

$$+ \Sigma Q_{\text{fusion}} + \Sigma Q_{\text{latent}} + \Sigma Q_{\substack{\text{sensible}\\ \text{gases}}} + \Sigma Q_{\text{losses}}$$

In order to calculate the total energy input it is required to know the thermal properties of the system and of the wastes. The thermal properties of the system are dependent upon design, and therefore, are omitted from the analysis. The balance of energy is required to incinerate the wastes, and is estimated as follows.

The net heats of combustion of the wastes cannot be calculated since the heats of formation of some of the wastes are not known. The gross heats of combustion are calculated as follows, using the quantities shown in Table 2.

Material	Mass gm/day	Heating Value at 1 atm, 18°C kcal/gm (Ref.3)	Q kcal
C	593.7	8.08	4797
H*	48.8	28.9	1410
S	0.3	2.17	1
			6208 kcal/day

The sensible heat of the wastes accounts for the thermal energy required to reach the melting, vaporization and/or ignition temperature. Water will vaporize at the sterilization temperature of 250°F (121°C), provided a pressure relief valve is provided to prevent the total pressure from exceeding 29.8 psia. For an assumed initial temperature of 60°F (15.6°C), the sensible heat added to water will then be 43.7 kilocalories per day. Polyethylene will melt at 260°F (126.7°C). The sensible heat required to heat food tubes and plastic bags is therefore 11.0 kilocalories per day. It is assumed that the other waste materials will be heated to temperatures as high as 1400°F without undergoing a change of phase or significant change in composition. The table below shows the sensible heat required to perform this heating.

Item	m (gm/day)	Cp (Ref. 4,5) (cal/gm°C)	Q (kcal/day)
Sponges	225	0.40	67.0
Paper	75	0.30	16.7
Feces	150	0.40	80.5
Bags and Paper	150	0.30	33.5
Edible Residue	37	0.20	10.0
Filters	300	0.40	89.3
Cartridges	75	0.35	19.5
Totals	1012 gm/day		317.5 kcal/day

* Free hydrogen is calculated by subtracting combined hydrogen from total hydrogen shown in Table 2.

The wastes which melt prior to either vaporizing or igniting consist of food tubes and bladders fabricated from polyethylene. The heat of fusion of this material is (Ref. 6):

$$\Delta H_{f \text{ polyethylene}} = 23 \text{ cal/gm}$$

$$\Sigma Q_{fusion} = \Sigma m \cdot \Delta H_f$$

$$= (150 + 30)23$$

$$= 4.14 \text{ kcal/day}$$

The free water content of the wastes is the only component assumed to be transformed from liquid to gas. The amount of heat required to accomplish this is:

$$Q = m\, h_{fg}$$

$$= 412.5 \text{ gm/day } (525 \text{ cal/gm}) \text{ at } 250°F$$

$$= 216 \text{ kcal/day}$$

It was determined that 1974 gm of O_2 is consumed in the incineration process per day if no excess O_2 is provided and all of the carbon is converted to CO_2. The quantities of gases evolved in the process, if cabin gas is used, will therefore be:

N_2 - 4950 gm/day

CO_2 - 5810 gm/day

H_2O(combined) - 728 gm/day

SO_2 - 0.6 gm/day

If no heat exchange exists between the existing gases and the incoming nitrogen and oxygen, the enthalpy of the waste gases can be calculated decrementally over the range of 250°F to 1400°F. Decrements are as follows: (assuming steady input of oxygen and nitrogen and steady exit of CO_2 and H_2O).

Decrement	Gas	m gm	Cp (Ref.7) cal/gm	t °F	(t - 60°F) °F	Q kcal
1	N_2	495	0.254	307	247	17.2
	CO_2	581	0.230		(137°C)	18.3
	H_2O	73	0.460			4.6
2	N_2	495	0.255	422	362	25.4
	CO_2	581	0.265		(201°C)	30.9
	H_2O	73	0.470			6.9
3	N_2	495	0.260	537	477	34.1
	CO_2	581	0.270		(265°C)	41.6
	H_2O	73	0.475			9.2
4	N_2	495	0.260	652	592	42.3
	CO_2	581	0.270		(329°C)	51.6
	H_2O	73	0.480			11.5
5	N_2	495	0.260	767	707	50.6
	CO_2	581	0.275		(393°C)	62.8
	H_2O	73	0.490			13.9
6	N_2	495	0.265	882	882	60.0
	CO_2	581	0.280		(457°C)	74.3
	H_2O	73	0.500			16.7
7	N_2	495	0.270	997	937	69.5
	CO_2	581	0.281		(520°C)	84.9
	H_2O	73	0.510			19.3
8	N_2	495	0.272	1112	1052	78.7
	CO_2	581	0.285		(585°C)	96.9
	H_2O	73	0.520			22.2
9	N_2	495	0.275	1227	1167	88.2
	CO_2	581	0.290		(648°C)	109.2
	H_2O	73	0.530			25.1
10	N_2	495	0.280	1342	1282	98.7
	CO_2	581	0.292		(712°C)	120.7
	H_2O	73	0.530			27.5
	Totals	11,490 gm				1,412.8 kcal/day

With these calculated thermal properties of the wastes, the energy balance becomes:

$$\Sigma Q_{input} + \Sigma(6208 \text{ kcal} - Q_{\text{heats of formation}})_{\text{net heats of combustion}}$$

$$= (372 \text{ kcal})_{\substack{\text{sensible}\\ \text{wastes}}} + \Sigma Q_{\substack{\text{sensible}\\ \text{system}}} + (4 \text{ kcal})_{\text{fusion}}$$

$$+ (216 \text{ kcal})_{\text{latent}} + (1412 \text{ kcal})_{\substack{\text{sensible}\\ \text{gases}}} + \Sigma Q_{\text{losses}}$$

or

$$\Sigma Q_{input} + \Sigma(6208 \text{ kcal} - Q_{\text{heats of formation}})_{\substack{\text{net}\\ \text{heat of}\\ \text{combustion}}} = 2004 \text{ kcal}$$

$$+ \Sigma Q_{\substack{\text{sensible}\\ \text{system}}} + \Sigma Q_{\text{losses}}$$

It is indicative from the above analysis that there is not sufficient information to determine the exact amount of energy required to incinerate the wastes. If the assumption is made that the net heats of combustion from the wastes were approximately equal to the sensible heat required to bring the system up to operating temperature plus the heat lost by the system, the required energy input needed to incinerate the wastes are 2004 kilocalories. If the incineration period is 12 hours the continuous power input would be 194 watts.

In the above assumption there is no heat exchange between the outgoing gases and the incoming gas. If an 80 per cent effective heat exchanger is used, the sensible heat required for increasing the incoming gases to ignition temperature is reduced to 282 kcalories per day. The overall power input for a 12-hour incinerating period would be reduced to 85 watts plus heat losses.

If pure oxygen is used instead of cabin gas the sensible heat requirement of the exiting gases is decreased from 1412.8 kcal/day to 848 kcal/day. If thermal losses to the system remain the same and an 80 per cent effective heat exchanger is used between the outgoing gas and the oxygen the power demand can conceivably be reduced to 74 watts over a 12-hour period.

Decomposition - Since thermal decomposition of wastes is defined as the thermal break-down of the wastes at reduced pressure without the use of oxygen, the energy balance will be:

$$\Sigma Q_{input} = \Sigma Q_{\substack{\text{sensible}\\ \text{wastes}}} + \Sigma Q_{\text{system}} + \Sigma Q_{\text{fusion}} + \Sigma Q_{\text{latent heat}}$$

$$+ \Sigma Q_{\substack{\text{sensible}\\ \text{gases}}} + \Sigma Q_{\text{losses}}$$

If it is assumed that the temperature of decomposition of the solid wastes is the same as the spontaneous ignition temperature when using incineration the following values will be the same for both processes: (temperature and pressure of the wastes increased to 250°F, 29.8 psia prior to venting to effect sterilization).

$$Q_{\substack{\text{sensible}\\\text{wastes}}} = 372 \text{ kcalories per day}$$

$$Q_{\text{fusion}} = 4 \text{ kcalories per day}$$

If the system design of the thermal decomposition system is approximately equivalent to that of the incineration system the sensible heat requirement of both systems and the heat losses from both systems will be equal.

The latent heats of vaporization of the wastes other than the free water are unknown and cannot be predicted. Also, the sensible heat requirement of the gases evolved from the wastes are not known. It can, therefore, only be stated that the energy requirement would be greater than 592 kcalories per day (57 watts in a 12-hour operating period).

Summary - In the foregoing analysis it is obvious that insufficient information exists regarding the thermal and chemical properties of the wastes. A certain number of assumptions were necessary in order to predict the oxygen consumption. Validity of these assumptions can only be achieved by experimental means. Assumptions were also made regarding the energy balance of the incineration process; some of the assumptions were broad and had to be resolved by experimental means. It was therefore necessary to design and fabricate an experimental model in order to determine the missing data and to confirm the data which was calculable. The following sub-section describes this experimental program.

Experimental Apparatus

Design

Structural Details - The design of experimental waste disposal unit was dictated by the premise that the single unit could be used for both incineration and decomposition tests. Figure 1 shows the detail assembly drawing, while Figures 2 and 3 show the completed unit.

The unit was installed in an insulated enclosure to reduce the heat loss to manageable values. Figure 4 is a photograph of the insulating enclosure with the unit installed. Johns-Manville MARINITE-36 insulating sheet was utilized for structural support, and J-M CERAFELT Type CFR 800 was used for bulk insulation.

Several design modifications were made during check-out testing of the system. The problems encountered were sealing and heater failure due to corrosion by the products of combustion of the heater lead-in wires.

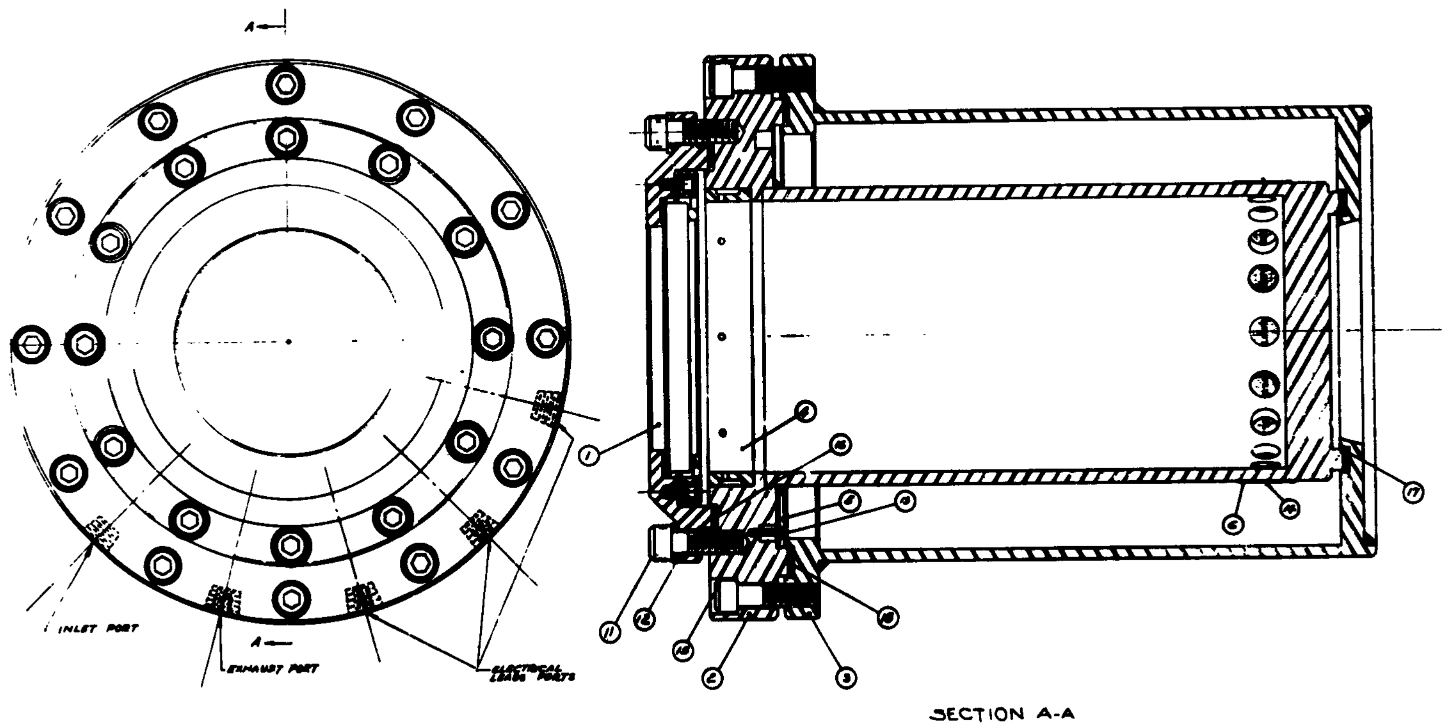

Figure 1 DETAIL ASSEMBLY DRAWING FOR EXPERIMENTAL WASTE DISPOSAL UNIT

Figure 2 EXTERNAL VIEW OF EXPERIMENTAL WASTE DISPOSAL UNIT

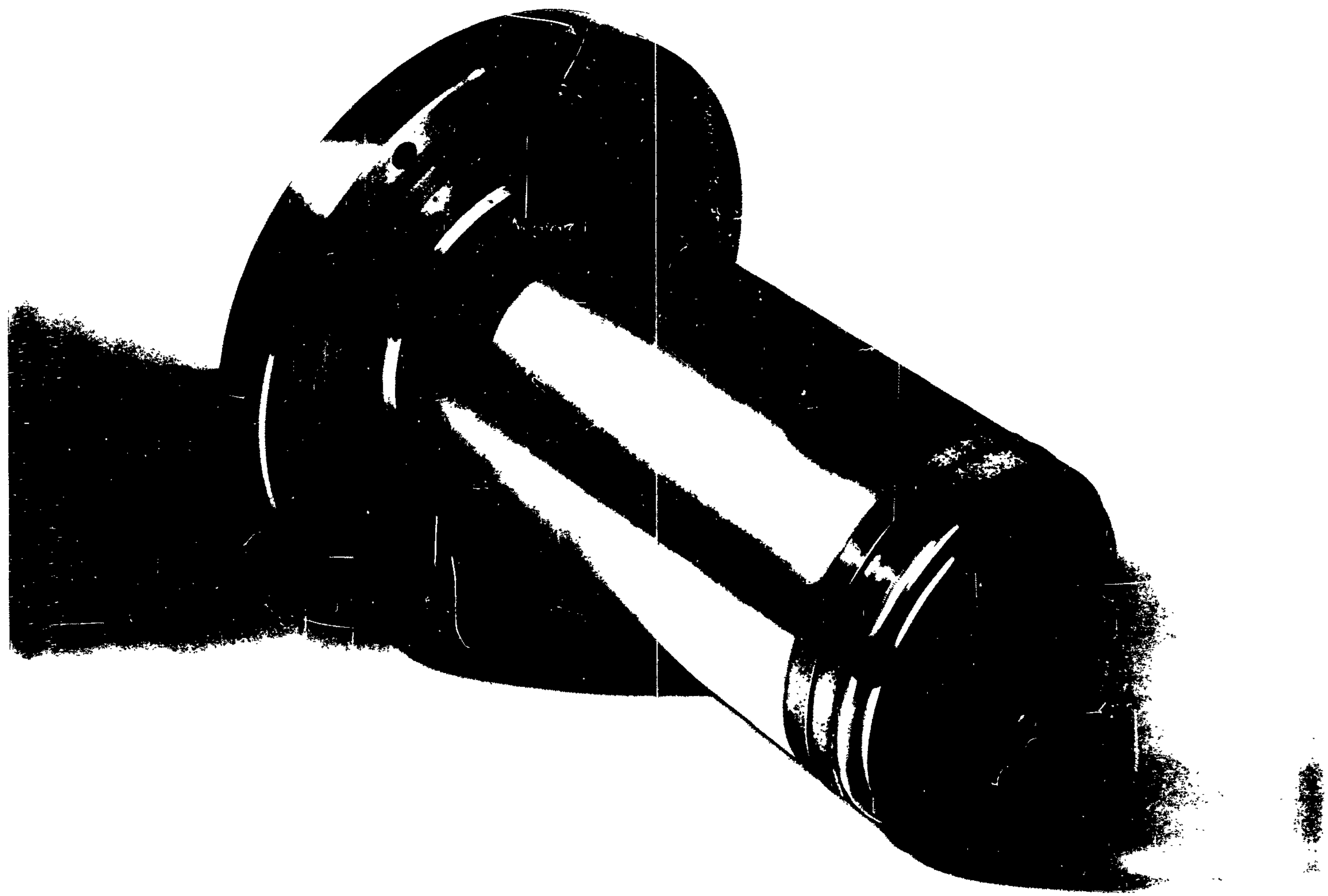

Figure [illegible] EXPERIMENTAL WASTE DISPOSAL UNIT WITHOUT OUTER SHELL

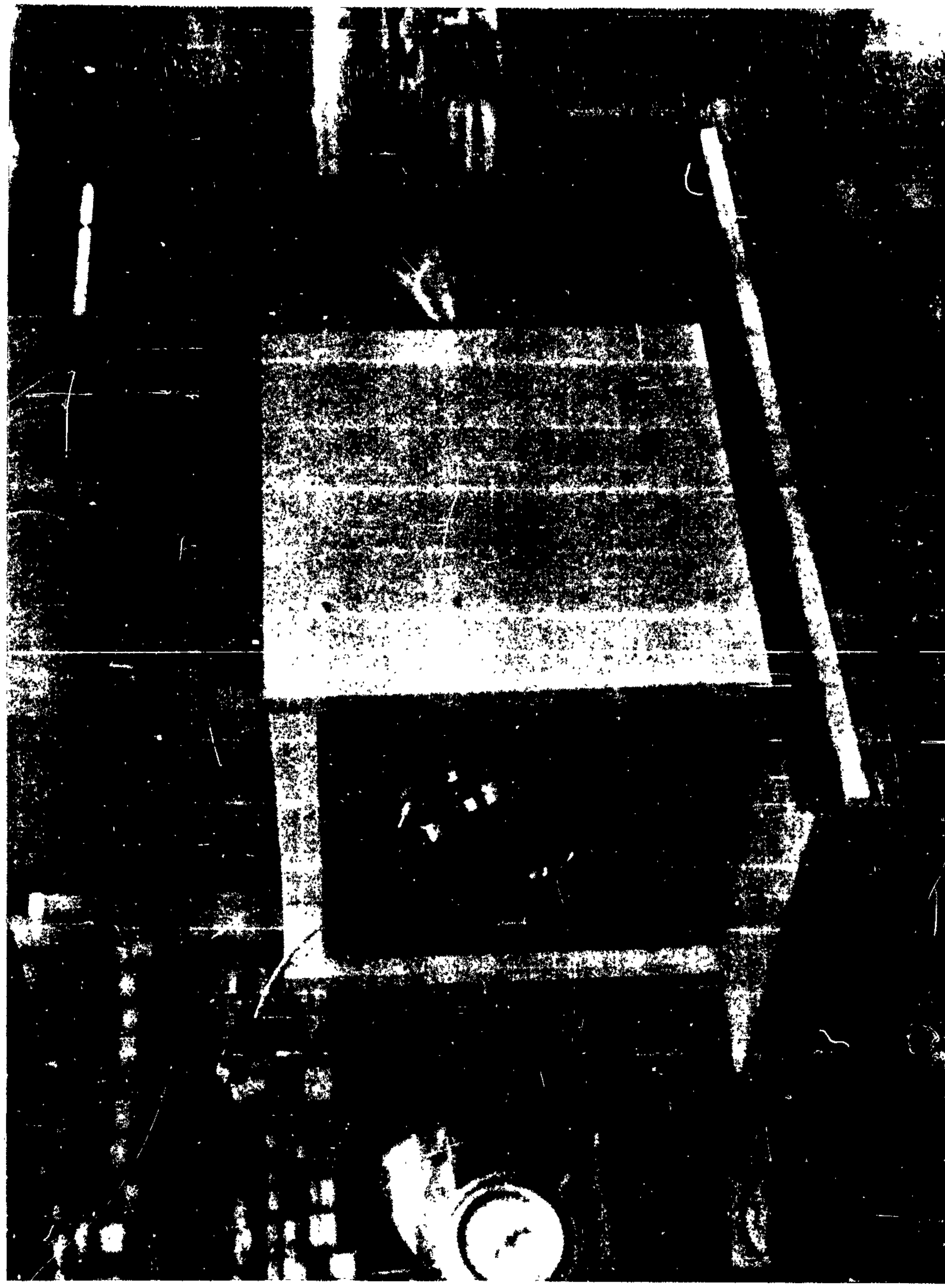

Figure 4 EXPERIMENTAL UNIT INSTALLATION

The inability to close the rear or solar surface seal was attributed to the difference in thermal expansion between the outer case, (Type 1020 steel), and the inner chamber (Type 304 stainless steel).

The second major problem encountered was corrosion of the copper lead-in wires to the heater. These wires, although covered with an insulating bead, were attacked by the combustion products to such an extent that they failed after every second test.

To alleviate these difficulties and also to conform with the design intent for the decomposition test several design changes were made, namely, (1) the outer case was removed, (2) the bypass ports at the rear of the incinerator chamber were plugged, and (3) the inlet and outlet connections rerouted to allow direct access to the internal chamber. Thus, the heater was exposed to ambient air (beneath the insulation) instead of the corrosive product gases.

Heater design - An electrothermal armoured 600-watt heater* was originally wrapped around the inner sheet. At atmospheric pressure, the heater operated satisfactorily, however, burn-out occurred under vacuum. The apparent cause of failure was, that too high a thermal resistance existed between the heater and the chamber under vacuum conditions. Under atmospheric conditions the air blanket around the heater supplied alternate paths for heat conduction which did not exist in vacuum. A new heater was fabricated from a high temperature heater alloy, Kanthal A-1, with a melting point of 2460°F. The wire was insulated with ball and socket ceramic beads and coated and bonded to the incinerator chamber with Thermon Grade T-3 heat transfer cement. Under vacuum this heater also failed.

It was then determined that Thermon cement is porous and its thermal conductivity properties are partly dependent on the air entrapped in the pores. Therefore, when used under vacuum this cement did not provide the thermal conductance required.

It was concluded that two changes were necessary to provide an efficient heating element.

1. Maximum surface contact between the heater and the incineration chamber.

2. The heater must be, at all times, under ambient pressure to ensure efficient heat transfer.

A third heater design was then formulated using Nichrome V ribbon. A 0.010-inch thick coat of aluminum oxide was flame sprayed on the outside of the incineration chamber to provide electrical isolation. When first installed, numerous electrical shorts were discovered between the heater and the chamber. A coating of Sauereisen cement was wiped onto the oxide to close the pores, and electrical isolation was attained. This scheme worked satisfactorily for four incineration tests. During the fifth test the heater shorted to the case causing failure. A 0.005-inch thick mica sheet was then installed as the electrical insulator. This arrangement has operated satisfactorily for the remainder of the tests.

* Source - Standard Scientific Supply Corp., New York, N. Y.

The final heater design consisted then of a 0.005-inch mica sheet double wrapped (0.010 total thickness) with a 45-foot tightly wrapped long ribbon heater (0.020-inch thick x 0.200-inch wide). Four, 14 gauge copper wires were used for the heater power connections. Ceramic beads were used for insulation.

Operation

Test Set-up - Figure 5 illustrates the experimental set-up. The output of the thermocouples was recorded by a 24-point Weston-Daystrom recorder, adjusted to record 6-points. The internal pressure was indicated by a water manometer for the low pressure mode and a 30-inch vacuum to 30 psig Bourdon tube gauge for the vacuum and high pressure modes. For the incineration tests the outlet gas was analyzed with an Orsat apparatus after passage through a dry ice-acetone cold trap.

Test Procedure

Incineration - The material to be incinerated was placed in the chamber and the door was sealed. The heater power was turned on with all inlet and outlet valves closed. As the unit temperature rose, the water in the waste was vaporized and the internal pressure increased to 15 psig at which time the internal temperature was at least 250°F. This was done to insure sterilization of the wastes and exit gases.

Both the inlet and outlet valves were then opened, and the pressure decreased to approximately 1 inch of water, which is the pressure drop through the unit at a 3000 cc/min inlet air flow rate.

The exit gases were analyzed periodically with the Orsat apparatus to determine their concentrations and to determine when combustion was completed.

Decomposition - For this type of waste disposal the Orsat apparatus was removed, the inlet connection closed and the outlet connected through a dry ice-acetone bath to a vacuum pump.

The initial stage of this mode of operation was identical to that for incineration; the outlet valve was closed, the power applied and the internal pressure allowed to build up to 15 psig. The outlet valve was then opened and the vacuum pump started. Periodically, the outlet valve was closed and the rise in pressure noted. When the pressure ceased to rise with the valve closed, it could be assumed that the volatile and pyrolytically generated vapors and gases were no longer present and the decomposition had ceased.

Testing

Initial Tests

Heat Loss Tests - For these tests the unit was sealed and the outlet valve opened. The heater power was turned on and the unit allowed to reach equilibrium temperature at which time the heat loss through the insulation was balanced by the power input from the electrical heater. This test was performed for three values of input power. Figure 6 is a plot of the results.

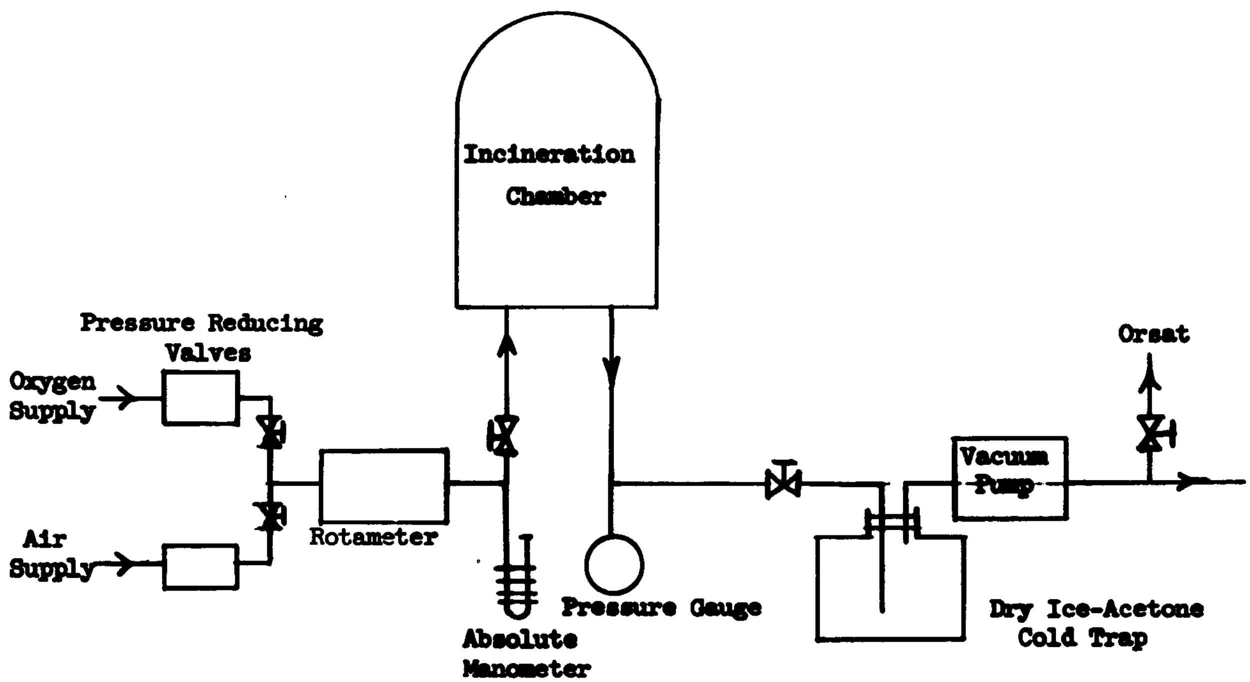

Figure 5 SCHEMATIC OF EXPERIMENTAL APPARATUS

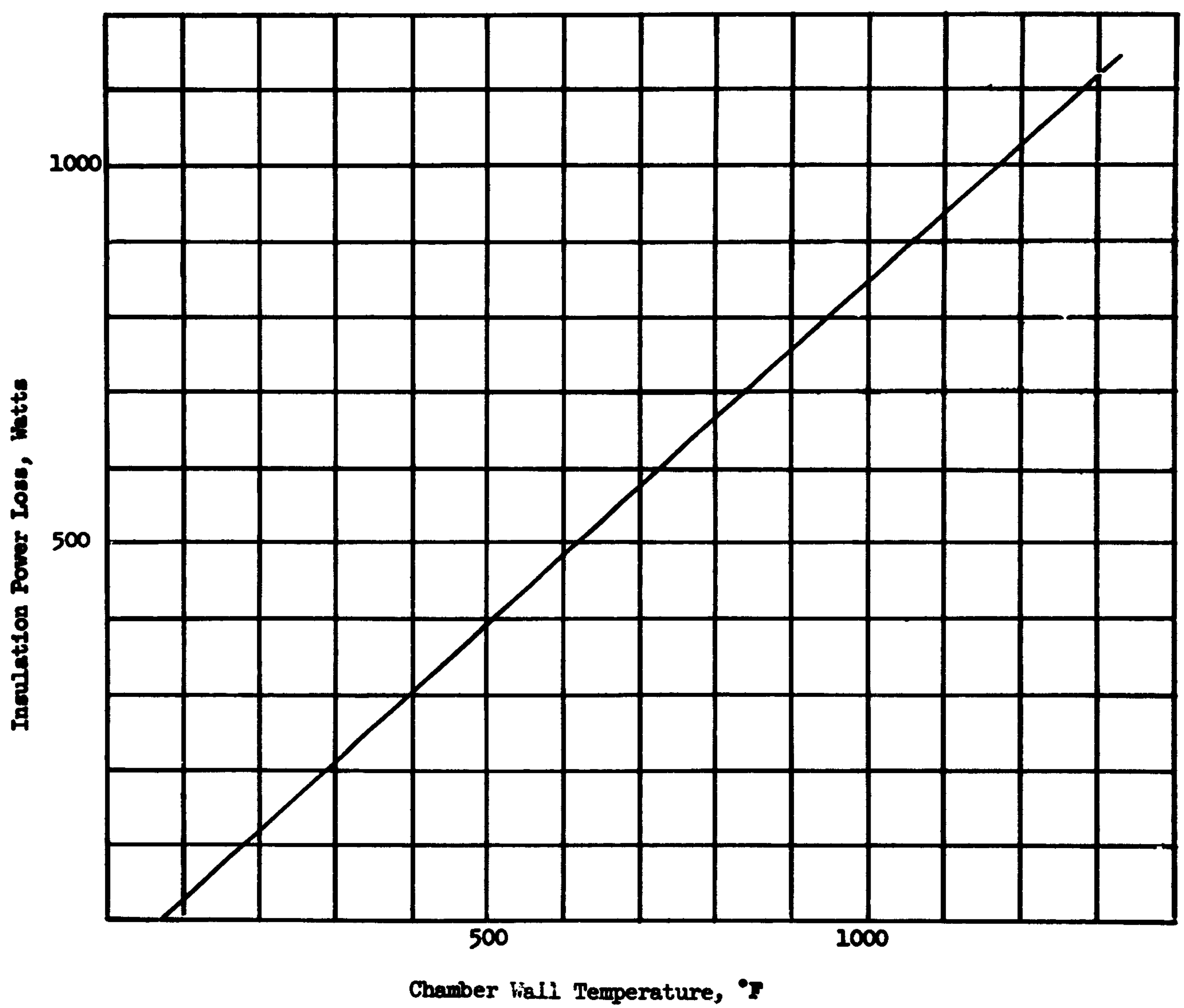

Figure 6 HEAT LOSS FROM EXPERIMENTAL WASTE DISPOSAL UNIT

Sensible Heat Content of Experimental Apparatus - For this test the unit was also sealed with the outlet valve opened. The power was turned on and the Variac adjusted to yield 1000 watts. The temperature history of the unit was then recorded. From the heat loss curve (Figure 6) and the temperature history, a power loss versus time plot was made (Figure 7).

An examination of the power balance equation for the situation under study indicates the following relationship:

$$\int_0^t P_{in}(t)dt = \int_0^t P(t)dt + A(T-T_o)$$

where $P_{in}(t)$ is the power input to the heater in watts

A constant of proportionality equivalent to specific heat times mass

T the chamber wall temperature

P_ℓ Power loss thru the insulation

Differentiation of the equation yields

$$P_{in}(t) = \frac{AdT}{dt} + P_\ell(t)$$

assuming P_{in} is constant and since P_ℓ is proportional to T, rearrangement leads to

$$\frac{dT}{dt} = B - CT \text{ where B and C are constants.}$$

The solution of this equation gives for T as a function of time

$$T = D(E - e^{-at}), \text{ where A, D and E are also constants.}$$

If P_ℓ, the heat loss factor, is proportional to T,

$$P_\ell = P_{\ell_o} (E - e^{-at})$$

An approximation to the curve, within 3%, was made with values for the constants as below

$$P_\ell = 774 (1 - e^{-.0089 t})$$

From this curve and the power input data, the calculated values for the constant A - sensible heat factor for the experimental apparatus - are as follows.

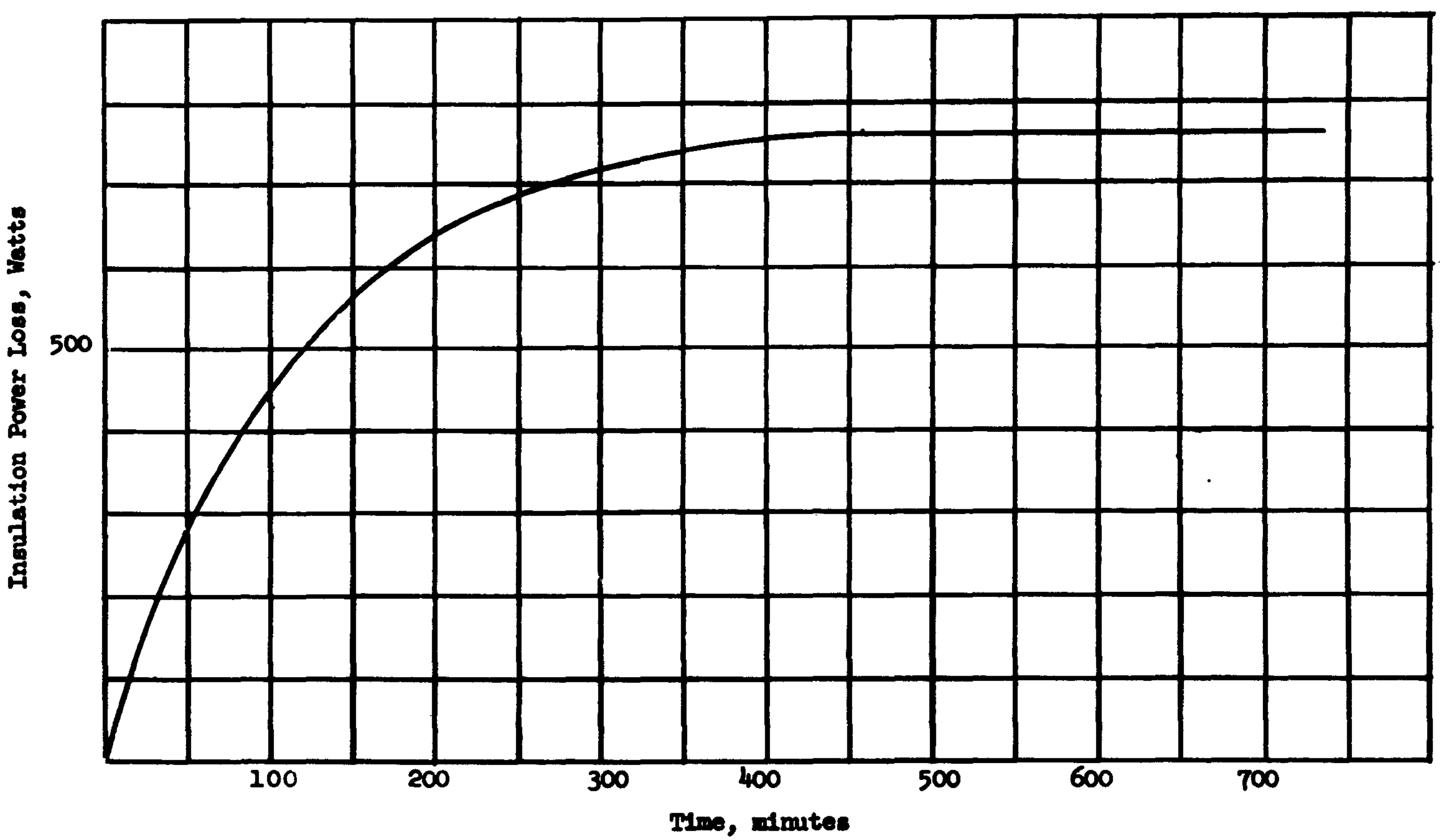

Figure 7 POWER LOSS HISTORY FOR EXPERIMENTAL WASTE DISPOSAL UNIT

Time, min.	Sensible Heat Factor, BTU/°F
50	3.24
150	4.96
250	5.21
350	5.37
450 (equilibrium obtained)	5.37

Incineration Check-out Tests - A series of tests were undertaken in order to determine optimum heater operating time and oxygen flow rate. Four tests were performed in accordance with the following combinations of parameters.

Run No.	Power, watts	Air Flow Rate, cc/min
1	600	1800
2	1000	3000
3	1000	1500
4	600	3000

The combustible sample for each test consisted of 20 gm of paper towel, one 9 gm cellulose sponge and 50 gm of polyvinyl chloride plastic sheet. For test runs 3 and 4, and in a rerun of number 2, 50 gm of polyethylene was substituted for the polyvinyl chloride because of the adverse action of the PVC combustion product on the copper leads to the heater.

The test periods were approximately 5 hours long. After each test the residue was examined, weighed and classified as to source. The results are tabulated in Table 3. Two tests were reruns, namely 3A and 2B. Test 3A was conducted because of an early malfunction in test 3. Test 2B was rerun to evaluate the difference in combustion for polyvinyl chloride and polyethylene.

The only tests run to completion were tests 2 and 2B where the residue consisted of a small quantity of noncombustible ash. Figure 8 presents photographs of the materials used for test 2B and the quantity of ash which remained. For the other tests listed, since the operation times are approximately equal, analysis was based on the per cent of sample consumed and the approximate time from ignition.

The initial ignition temperature appears to be approximately 500°F. Comparison of the results for runs 2B and 3A indicates that oxygen flow rate has a very significant effect on the disposal of polyethylene.

Figure 8 PHOTOGRAPHS OF WASTES USED AND RESIDUE REMAINING IN TEST 2B

TABLE 3

Results of Initial Tests

Test No.	Peak Temp.	Time	Residue	&	Probable Source	Consumed
1	616°F	4.7 hr	2.6 gm		Ash & carbon from paper.	93%
			17.0		Partially burned plastics	67
2	905	5.5	0.5		Black ash-PVC	100
			0.5		White ash-paper	100
			0.15		Yellow ash-sponge	100
3	753	1.8	49		Polyethylene	
			7		Sponge-black ash	
			14		Paper-white ash	
3A	888	4.7	40		Polyethylene	20
			1		Carbon from sponge	89.2
			2		Paper ash & carbon	
4	601	5.0	42		Polyethylene	16
			0.9		Paper & Sponge ash	97
2B	940	6.0	0.7		Black ash-Polyethylene	100
			0.6		White ash-paper & sponge	100

Incineration Tests

Incineration Test Using Air - The incineration test was conducted using a waste sample consisting of the following materials:

Material	Weight, gms	Weight of Constituents, gms				
		C	H	O	N	Ash
Feces	391	44.6	6.8	6.3	27	46
Polyethylene	112	96.0	16.0			
Paper	74	32.9	4.5	36.6		
Polyurethane	193	137.5	19.0	30.5	6	
Totals	770	311.0	46.3	73.4	33	46

Remainder H_2O - 260.3 grams

This quantity of material completely filled the combustion chamber. The wastes used in this test have a higher proportion of feces than shown in Table 1 (type and mass of wastes separated from cabin each man-day). The greater amount of feces replaces the edible residue portion and also provides a maximum operating test for the system.

Test Procedure - The waste sample was placed in the chamber and the chamber was sealed. The inlet and outlet valves were both closed. The power was turned on and set at 1000 watts.

As the system heated up, and the water vaporized, the pressure within the unit increased until it reached 15 psig. At this pressure the vaporization temperature of water is 250°F.

When the pressure reached 15 psig or 30 psia the pressure was released by opening the exhaust valve, and inlet valve was adjusted to obtain an air inflow rate of 3000 cc/min.

Periodic analysis of the exit gases was performed using an Orsat apparatus. When the internal temperature reached 1180°F the electrical power to the heater was reduced to 850 watts, which was sufficient to overcome heat losses and to maintain the temperature constant.

Results - The instantaneous values for the composition of the exit gases were determined by analysis. Based upon these values, a set of curves were plotted for each important constituent. These curves are presented as Figure 9. From these plots the total quantity of carbon dioxide, water and carbon monoxide produced was determined and compared with the total oxygen consumed. These figures are presented as Table 4 with the breakdown into constituent elements.

TABLE 4

Quantity of Gas Produced During Air Incineration Test

	Total lb	C, lb	H, lb	O, lb
Carbon dioxide	0.494	0.135		0.359
Water	0.286		0.032	0.254
Carbon monoxide	0.039	0.017		0.022
Totals		0.152	0.032	0.635

The total quantity of oxygen consumed was 0.668 pounds.

Agreement of the quantity of oxygen used with the quantity of oxygen in the product gases is within approximately 5 per cent.

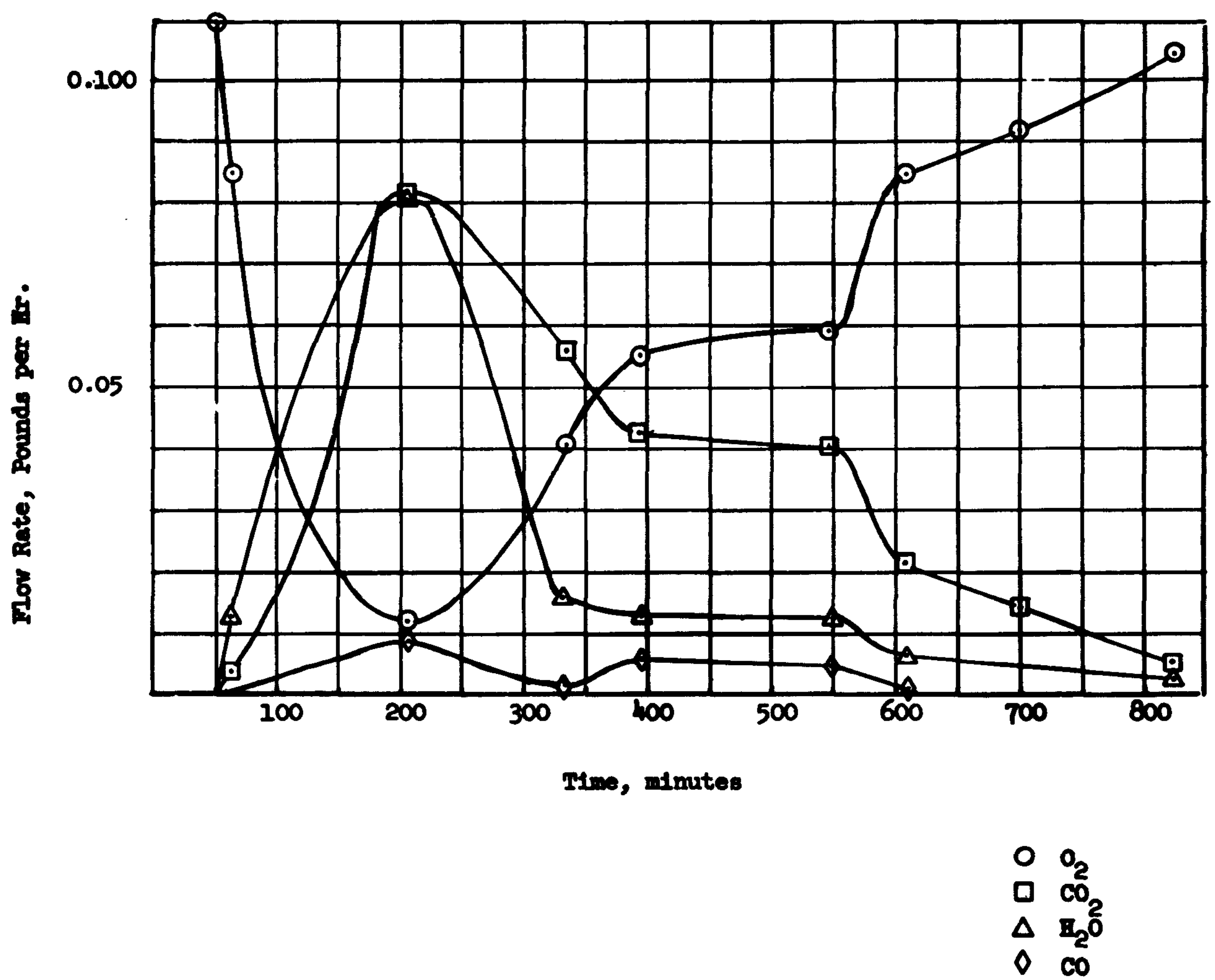

Figure 9 COMPOSITION OF EXIT GASES

When the quantity of carbon consumed, based on Figure 9, is compared with the total quantity present, it is apparent that only about 25 per cent can be accounted for. After the experiment it was noted that some solid material, about 7 gm, (probably recondensed polyethylene) had been deposited in the exhaust tubes. It is apparent therefore that pyrolysis and vaporization of the plastics had occurred during combustion.

The energy liberated by the combustion could not be calculated directly. However, analysis of the power input, the power loss through the insulation, and energy stored in the unit as sensible heat was used to determine the energy difference between the energy liberated in combustion and the energy carried away as sensible and latent heat by the combustion products. The value was calculated as -1930 Btu. That is, 1930 Btu more energy is carried away by the combustion products than is generated in combustion of 1.7 pounds of waste. The specific energy requirement for combustion with air at atmospheric pressure is therefore -1135 Btu/lb.

The energy required to raise the materials to the ignition point was based upon the difference in energy input and the energy lost by radiation and stored in the experimental apparatus. The ignition temperature was taken as 700°F (internal temperature), the point at which the temperature-time curve for the incineration process indicates a change in the rate of change of temperature with time (d^2T/dt^2). The temperature-time plot for the period under discussion is presented as Figure 10. The time of occurrence is 75 minutes after ignition.

The energy unaccounted for by either energy loss through the insulation or energy stored in the experimental apparatus (sensible heat factor for the experimental unit) is 670 Btu. (This energy must then be the energy stored in the wastes at the ignition temperature.) For the 1.7 pound of material and 640°F temperature rise this energy value reflects an experimental sensible heat factor of 0.625 Btu/lb°F.

Oxygen Incineration - This test was conducted to determine the effects of diluent gases on combustion efficiency and rate. The test apparatus was altered by the addition of a vacuum pump, a needle valve on the outlet line, an absolute manometer and a supply of pure oxygen. The conditions of the test specified an absolute pressure within the incineration chamber of 160 mm Hg, the partial pressure of oxygen in air at atmospheric pressure. This was to abrogate any effects of partial pressure of the oxygen on the burning rate. The oxygen flow rate was 0.072 pounds per hour for 7.5 hours and 0.122 pounds/hr for the remaining 3 hours of the test. The oxygen flow rate during the air test was 0.11 lbs/hr.

Test Procedure - The procedure of test was identical to the procedure used in the air incineration test. The unit was loaded with the waste sample and sealed. The test sample consisted of the following materials.

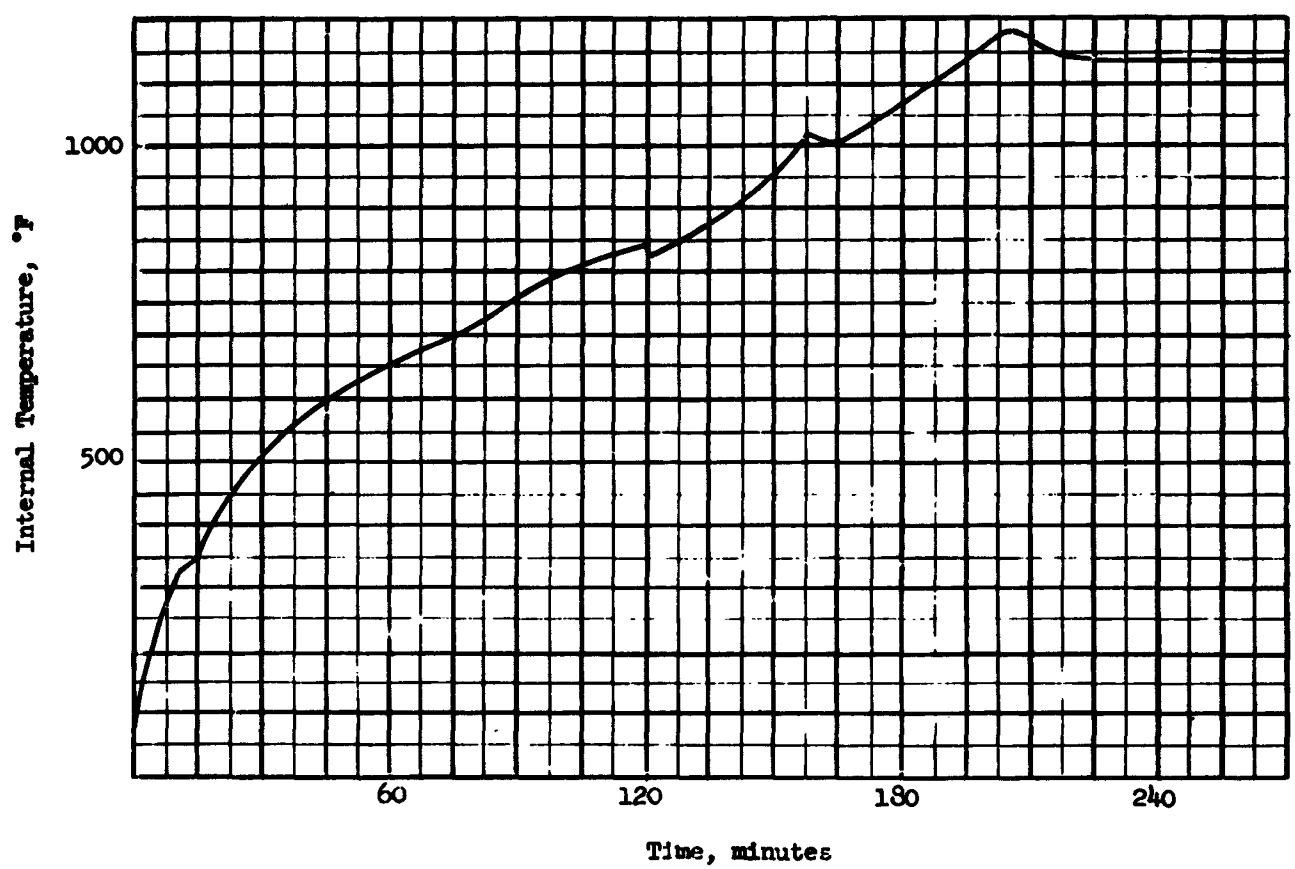

Figure 10 TEMPERATURE-TIME PLOT - INCINERATION

Material	Weight, gms	Weight of Constituents, gms C	H	O	N	Ash
Feces	382	43.6	6.6	6.1	26.4	45
Polyethylene	110	94	15.7			
Paper	75	33.3	4.5	37.1		
Polyurethane	203	14.5	20.0	3.2	6.3	
Totals	770	315.9	46.8	75.2	32.7	45

Remainder H_2O - 255 grams

With all valves closed the unit was heated until the internal pressure reached 30 psia. The outlet valve was opened slightly to maintain the pressure at this value for 10 minutes. The outlet valve was then opened and the vacuum pump started. The pressure was reduced to 160 mm Hg. The oxygen was turned on and the flow rate set at 1940 cc/min at 1060 mm Hg pressure. The exhaust gases were periodically analyzed with an Orsat apparatus to determine the exit gas composition.

Results - The instantaneous values of exit gas constituents obtained from the analysis are given in Figure 11. Based upon these plots, the quantities of the gases generated are listed in Table 5 below.

TABLE 5

Quantity of Gas Produced During O_2 Incineration Tests

	Total lb	C, lb	H, lb	O, lb
Carbon dioxide	0.886	0.242		0.645
Carbon monoxide	0.116	0.050		0.067
Water	0.321		0.036	0.285
Totals		0.292	0.036	0.997

The quantity of excess oxygen as determined by the analysis was 0.125 pounds. Therefore the total oxygen content of the exit gases was 1.12 pounds. The actual oxygen usage was determined by weighing the cylinder before and after the test. The difference in weight was 1.17 pounds. The error in the analysis is therefore 4 per cent.

The weight of material collected in the cold trap excluding water was 160 grams. This residue consisted of a black, waxy substance and an oil.

Analysis of the power input, heat loss through the insulation and the sensible heat factor for the apparatus yields a net energy gain from combustion and the energy loss in the latent and sensible heat of the exit gases. The result reduces to a specific energy gain of 1130 Btu/lb of waste.

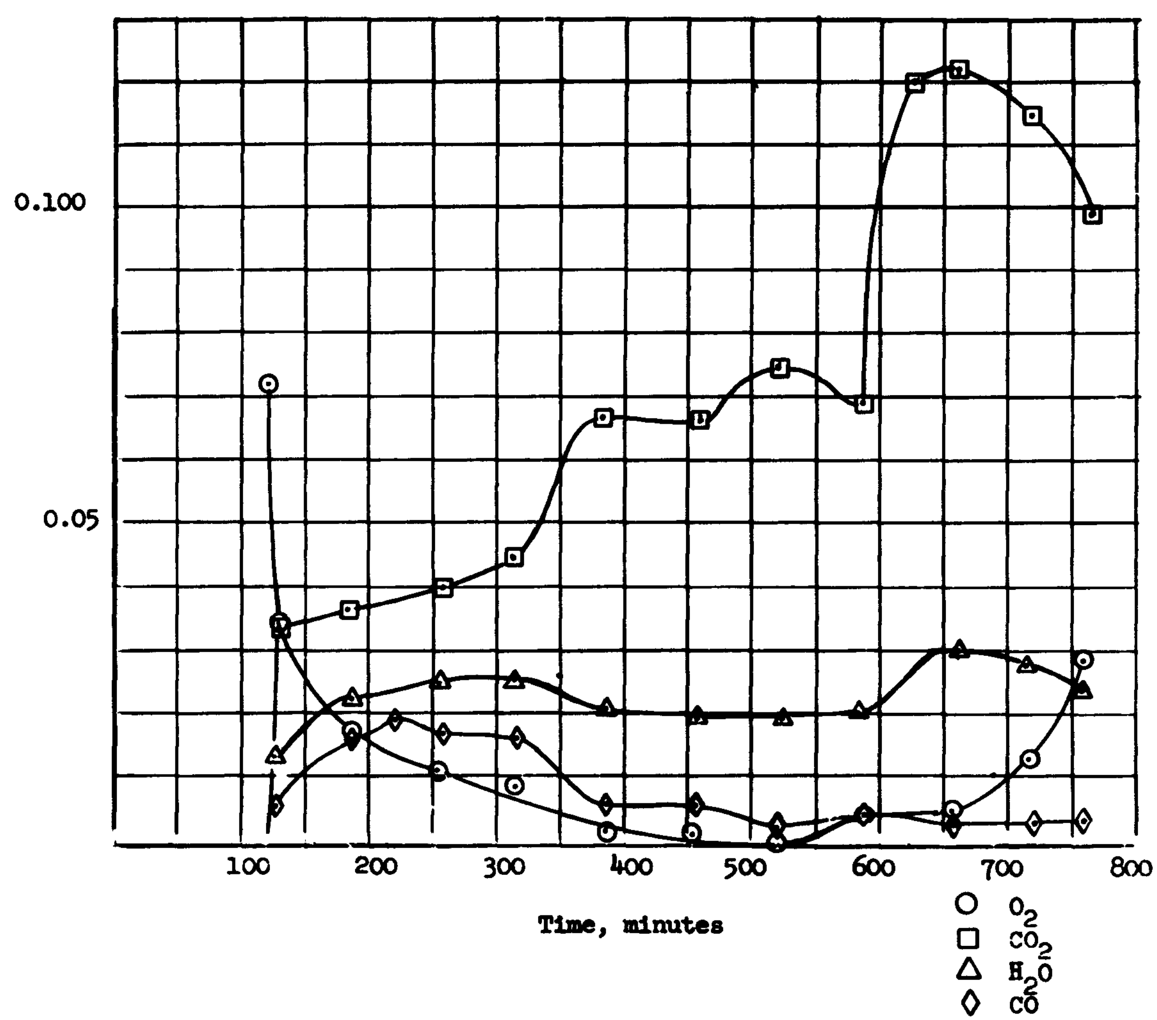

Figure 11 EXIT GAS COMPOSITION - OXYGEN TEST

Vacuum Decomposition

A vacuum decomposition test was conducted to determine the feasibility of this method of waste disposal. In theory, under vacuum and high temperature, the materials are decomposed into gaseous products, which exhaust to vacuum. This test was conducted to determine the energy required for this process, and the time and temperature necessary for efficient conversion.

Test Procedure - The waste sample used in the test consisted of the items listed below.

Material	Weight, gms	Weight of Constituents, gms				
		C	H	O	N	Ash
Feces	155	13.6	2.7	2.5	10.7	17.5
Polyethylene	160	137.0	23.0			
Polyurethane	217	155.0	21.0	34.0	7.0	
Paper	75	33.0	4.5	36.5		
Totals	607	338.6	51.2	73.0	17.7	17.5

The outlet valve was closed and 1000 watts of power applied to the heater. The vaporization of the water increased the internal pressure to 15 psig. At this point the pressure was relieved and the vacuum pump started. The pressure within the unit was reduced to 25" Hg vacuum. A temperature-time plot was made of the outlet gas temperature, the chamber wall temperature and the internal temperature of the gases. The test continued for 12-1/4 hours. The terminal point for this test had been assumed to be at the time the vacuum pump output would be essentially zero, and with the exhaust valve closed, the pressure within the chamber remained constant.

Results - The residue in the chamber was weighed and found to consist of 74.3 gms of charcoal type carbon with a trace of white ash. During the test, it was noted that the exhaust tubes were being clogged. The heat exchanger tube was removed when it became completely plugged. The exhaust system was shortened, insulated, and finally heated to alleviate this difficulty. It was found upon examination that the decomposition process resulted in the creation of heavy fractions, volatile at the temperature existing inside the chamber but which solidified at the lower temperatures of the exhaust tubes. These compounds resembled a brown wax.

The energy required for decomposition was determined analytically from the energy input, the energy lost through the insulation, and the energy stored in the unit as sensible heat. The energy value calculated included both the energy required for the decomposition and the energy carried away by the exhaust products as heat of vaporization and sensible heat. The value determined was 5850 Btu for the total quantity or 4350 Btu/pound.

Conclusions

The experimental procedure was designed to determine the specific heat of the wastes, and the power requirements for both the incineration and vacuum decomposition techniques of waste disposal. The values as determined by experiment are as follows:

TABLE 6

Value of Parameters Determined by Experiment

Specific heat of waste sample	0.625 Btu/lb°F
Energy required for incineration with air at atmospheric pressure	-1130 Btu/lb
Energy generated by incineration with oxygen, 160 mm Hg	+1135 Btu/lb
Energy required for decomposition	-4350 Btu/lb

Since in either technique of waste disposal, incineration or decomposition, it will be necessary to first heat the wastes for sterilization, the initial power requirement will be the same. However, once sterilization has been accomplished, assuming a 12-hour operation time for the conversion of a 3-man day load, vacuum decomposition requires more power (470 watts) than incineration with pure oxygen.

Optimization for weight, with a power weight penalty of 6 watts/lb and an oxygen requirement of 2.4 pounds of oxygen per 3-man day load was performed for the disposal techniques under study. A comparison of candidate systems is given in Figure 12.

In summary, oxygen incineration with oxygen either stored in fiberglas spheres or as a supercritical fluid has a smaller launch weight penalty than thermal decomposition for missions less than 13 days, assuming a SNAP VIII power source.

With both techniques, vaporization and pyrolysis of the plastics in the waste results in the formation of solidifying fractions. These materials could in time clog the outlet tubes if allowed to condense. The gases must therefore be rejected at high temperature, and little allowance for energy recovery through heat exchange between the inlet and outlet gases appears possible.

In addition, the presence of these fractions in the exhaust gases from incineration precludes the possibility of recovery of the water and oxygen entrapped in the exhaust. The products from both incineration and decomposition would best be rejected from the vehicle.

The thermal radiation method of heating was not investigated during this phase since the main parameters of interest were the energy requirements for the various techniques of disposal, but was scheduled to be investigated with the fabricated laboratory model using MRD's Strong Solar Simulator.

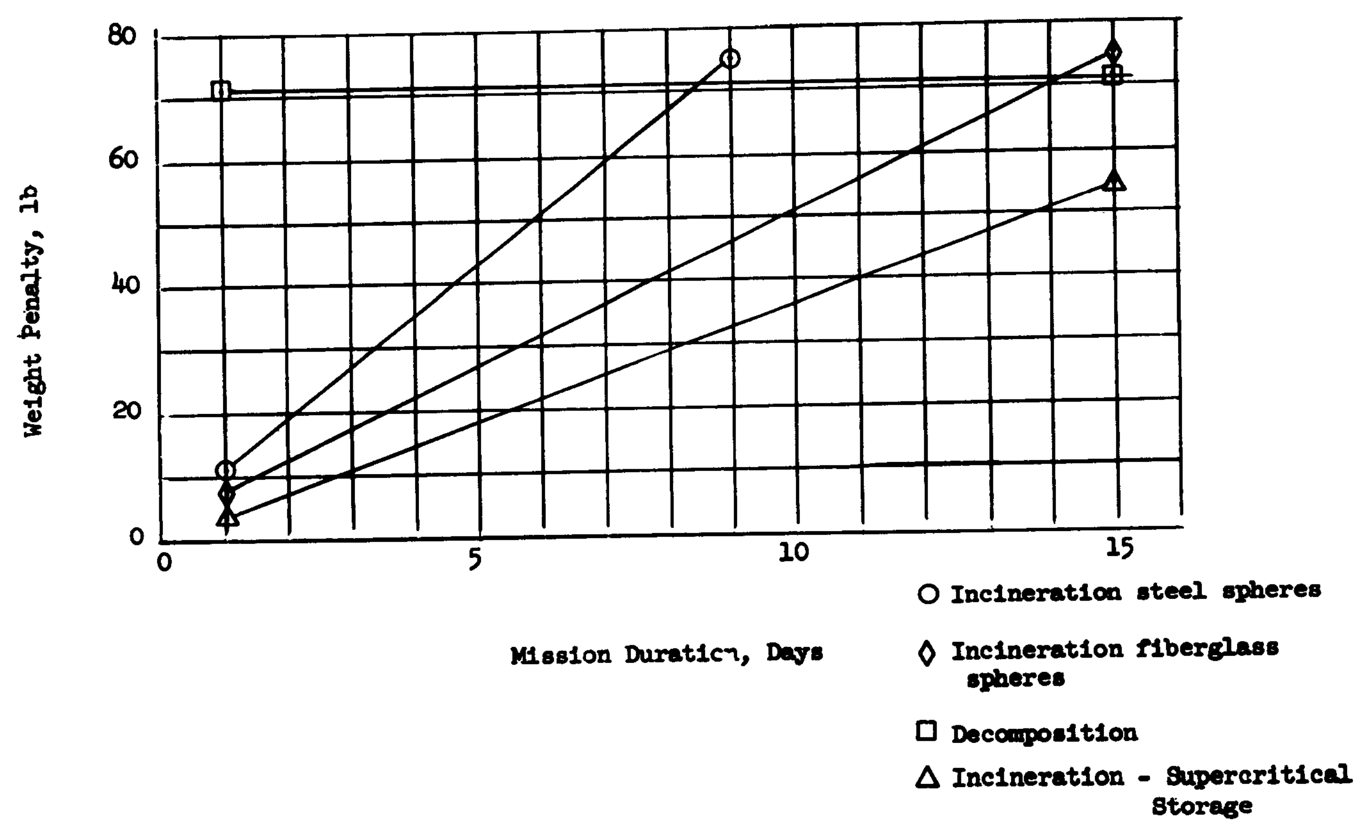

Figure 12 COMPARISON OF LAUNCH WEIGHT PENALTIES FOR CANDIDATE WASTE DISPOSAL SYSTEMS

Preliminary Design

Figure 13 shows the preliminary design recommended for a flight prototype waste incinerator that would use pure oxygen. The principle design features provided are as follows.

1. The incineration chamber volume (855 cubic inches) is sufficient to accommodate 3.5 pounds of waste.

2. The overall length (closed) is only 24 inches so that the unit could be mounted in a 7.5-foot diameter horizontal chamber without extending into a 33-inch wide aisle.

3. A quick-opening, insulated door is provided for loading wastes.

4. The resistance heating element is wound around the outside of the chamber to prevent oxidation by combustion products and avoid the occurrence of local hot spots during operation at reduced pressures.

A weight trade-off study was made to determine the optimum thickness of Johns-Manville Min-K insulation, assuming an auxiliary power weight penalty of 6.7 watts per pound (SNAP VIII with space radiation). The results tabulated below show that 3 inches of insulation is considered the optimum thickness.

Insulation thickness, inches	Heat loss, watts	Total weight, lbs power supply and insulation
1	517	91.3
2	310	64.5
3	200	53.9
4	155	56.6

From the preliminary design drawing it was estimated that the incinerator would impose the following penalties on an aerospace vehicle.

Total weight	50 pounds
Total volume	2.5 cubic feet
Power (for 12 hours each day)	110 watts

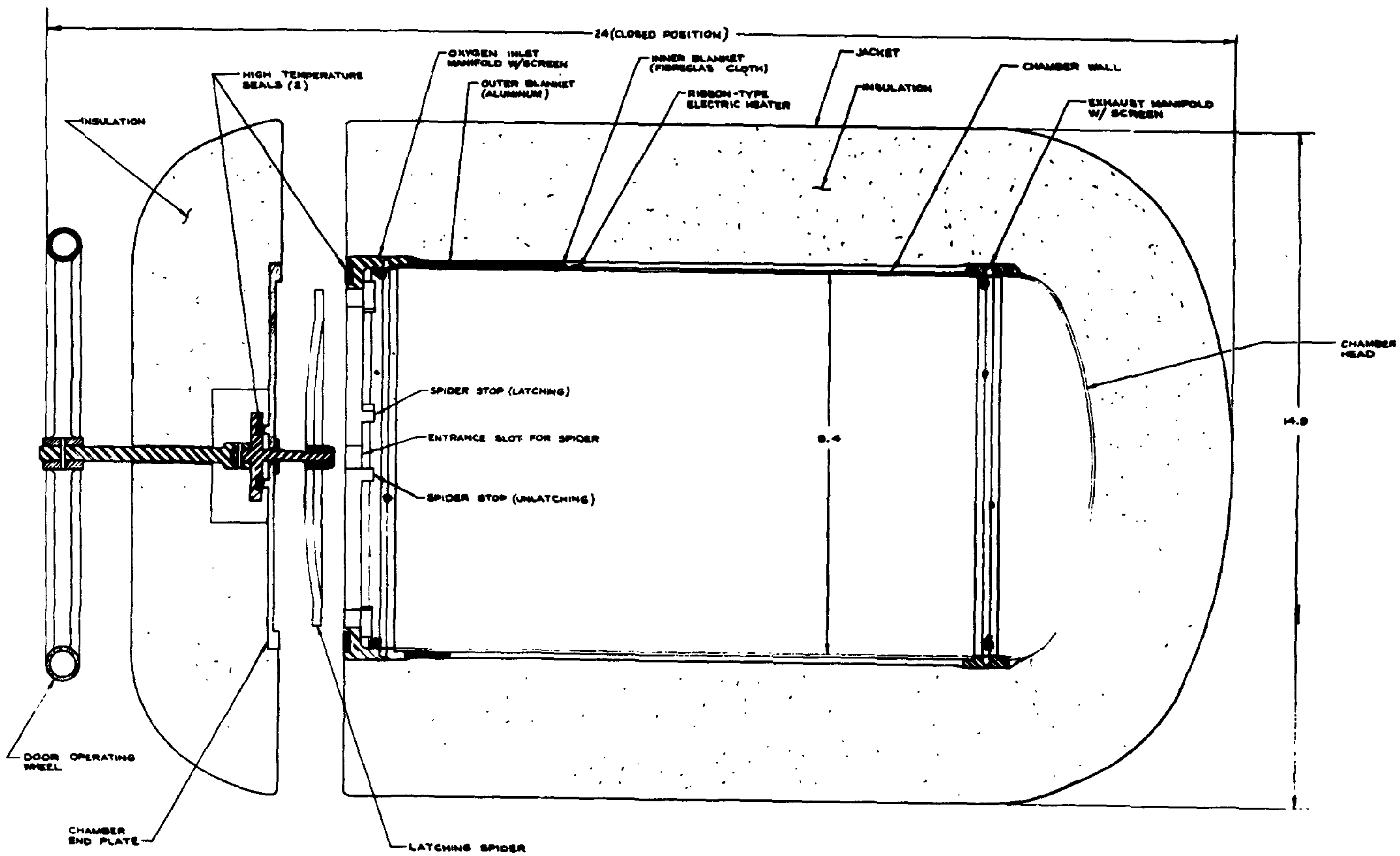

Figure 13 PRELIMINARY DESIGN OF LABORATORY MODEL INCINERATOR

SECTION 3

DESCRIPTION OF THE LABORATORY MODEL INCINERATOR

A laboratory model waste incinerator, based upon the preliminary design shown in Figure 13, was designed in detail and fabricated by the MRD Division for evaluation purposes. Figure 14 shows the completed unit. The system weighs 81 pounds and occupies a volume of 3.1 cubic feet. The detail description of the system design is as follows. The display and control panel indicates internal pressure, internal temperature and heater power "on". Flow control valves are provided for oxygen and exhaust flows. The large handle shown controls a 1-inch diameter ball valve, good for 1000°F service with an oxidizing fluid, that is provided for blowing ash overboard from an aerospace vehicle. The three position heater switch enables an operator to select either the high, low or off mode of operation.

Mechanical Design

Figure 15 shows an assembled view of the evolved Waste Disposal System. Waste is processed in the inner shell - which is a stainless steel cylinder welded to a spun-stainless, eliptical head at the rear end, and a flat plate at the front or loading end. An oxygen distribution groove is cut into the front plate, which is covered by a flat ring to form a manifold. Twelve equally spaced oxygen passage holes are drilled into the ring for equal distribution of the incoming oxygen.

At the opposite end of the cylinder an exhaust manifold is formed by a welded assembly of a circumferential screen and the cylinder itself. The screen filters exhaust flow to protect the relief valve. A seal groove is cut into the flat plate at the loading end. The groove is machined to apply a concentrated load on a standard Flexitalic Hi-Temperature Gasket No. R4-1N. The gasket is compressed in the groove by a similar load-concentrator on the loading hatch. The gasket alone locates the hatch sealing surface axially. Tolerance stack-up, deformations, creep, or other axial strains do not affect the gasket's ability to seal. The latching mechanism applies the axial force through a 3-legged spider keyed to a lock ring to hold a seal during the "pressure" portion of the cycle. The spider legs enter and leave the ring through loading slots. Stops are provided to locate the legs in line with the slots when the hatch is ready to be moved in or out, enabling both opening and closing of the hatch by manipulating the wheel only. To open the hatch, the wheel is turned counter-clockwise releasing the axial force through the spider. Then the spider turns with the wheel until the legs are "in line" with the loading slots in the ring. The hatch assembly can then be pulled from its nest. Similarly, closing the hatch is accomplished by first inserting the hatch, then turning the wheel clockwise.

Because of the excessive time and cost required to install Johns-Manville Min-K insulation the incinerator was provided with Thermocil. This design change increased the size and weight of the model by 0.6 cubic feet and 31 pounds, respectively.

The outer skin and insulation on the rear end of the unit can be removed to expose the elliptical end of the incineration chamber for heating the unit with concentrated solar energy.

Figure 14 PHOTOGRAPH OF LABORATORY MODEL INCINERATOR

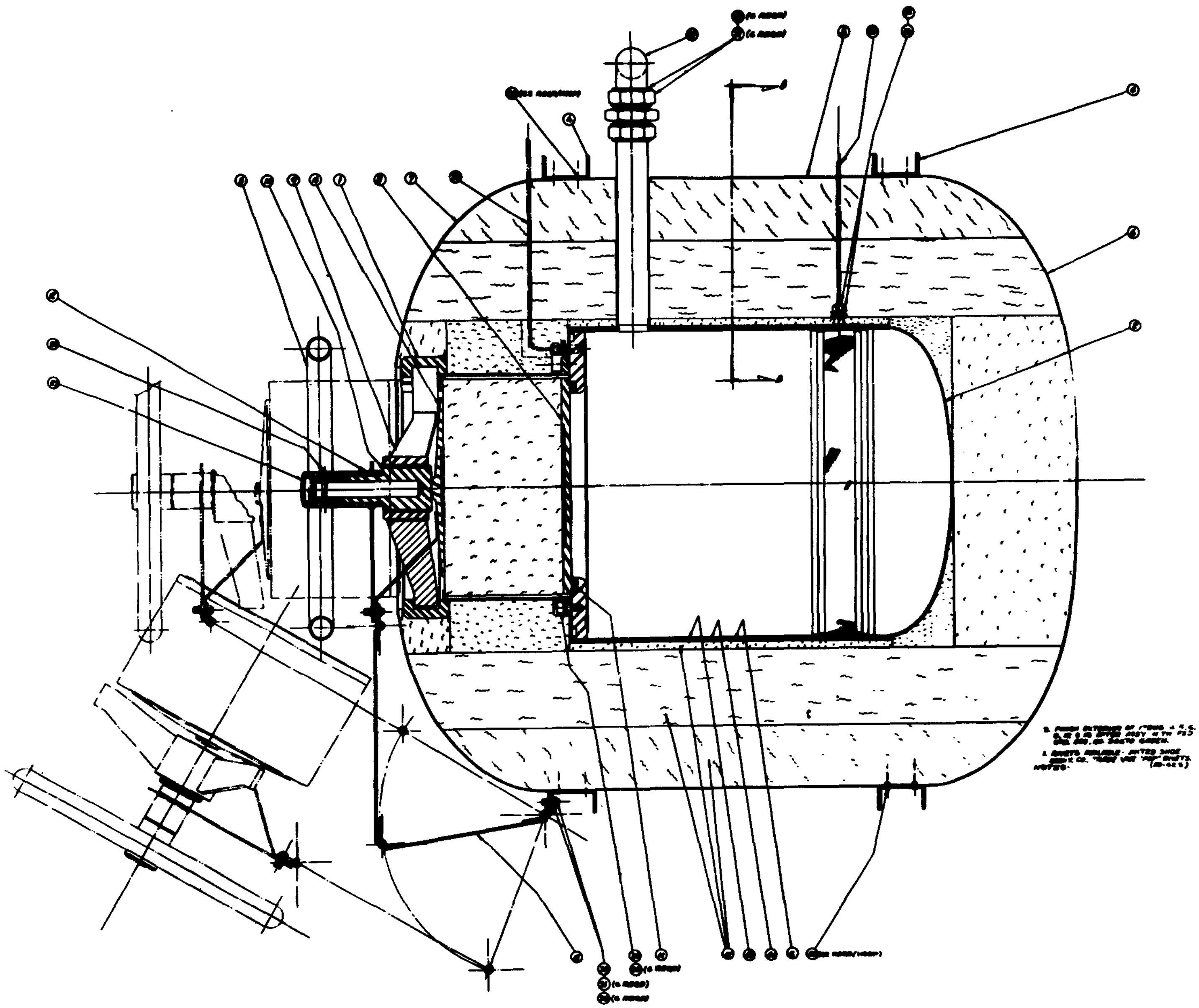

Figure 15 DETAIL DESIGN ASSEMBLY FOR LABORATORY MODEL INCINERATOR

Electrical Description

Heating of the wastes is provided by resistance heaters wrapped around the cylindrical portion of the chamber. The heater assembly consists of Nichrome V ribbon wrapped over 0.010 thickness mica sheet and covered with woven fiberglas cloth. During the preliminary design study it was demonstrated that this heater design was satisfactory for use at voltages at least four times higher than 28 volts. A schematic diagram showing the connection of the heaters to the power supply is shown as Figure 16. A thermoswitch is wired into the circuit to control incineration temperature. The heater cut-off temperature is manually selected by turning a set-screw at the top of the switch. The switch was adjusted to maintain 1050°F ± 50°F, as shown on the panel, a value optimized between successful incineration and heat loss. This heater has been operated at temperatures as high as 1200°F.

Two "on" positions are provided in the power switch. It is intended that the high position be used to reach operating temperature then switch to the low position to hold at temperature. However, the unit will reach operating temperature in the low position in a proportionally longer time, and the thermoswitch operates with power on high as well as low. Therefore, the unit may be run through a complete cycle with the power on low when it is desired to keep peak power low. Or it may be run on high when an accelerated cycle is desired. The power consumption at 28 volts DC with the switch in the high position is 400 watts, in the low position the power consumption is 375 watts. During the development tests the thermoswitch was closed approximately 50 per cent of the time after warmup. Average power, then, is approximately 200 watts.

Major Component Description

A pressure gage is mounted on the panel to indicate incineration chamber pressure relative to one atmosphere. If the incinerator is to be used at an ambient pressure other than standard, the gage must be recalibrated. The range is from 30 inches Hg vacuum to 30 psig, although normal operation is not above 15 psig. That range can be moved to 0 psig to 30 psig without damage to the instrument if the gage operates in a vacuum. The gage can be readily disassembled from behind to gain access to the printed diskface. The instrument has a 300 series, stainless steel Bourdon tube and fittings, and should not be replaced by an instrument with less corrosion resistance.

Only two connections to the unit are necessary for normal operation, though it might be desirable to add various instruments during laboratory evaluation. A two-conductor cable with an appropriate Amphenol connector at the end attached to the unit, is supplied. Soldered terminals are provided at the other end for connection to a 28-v d.c. power source. Both conductors are insulated from the unit. A 1-inch connection is provided for an evacuation and vent line.

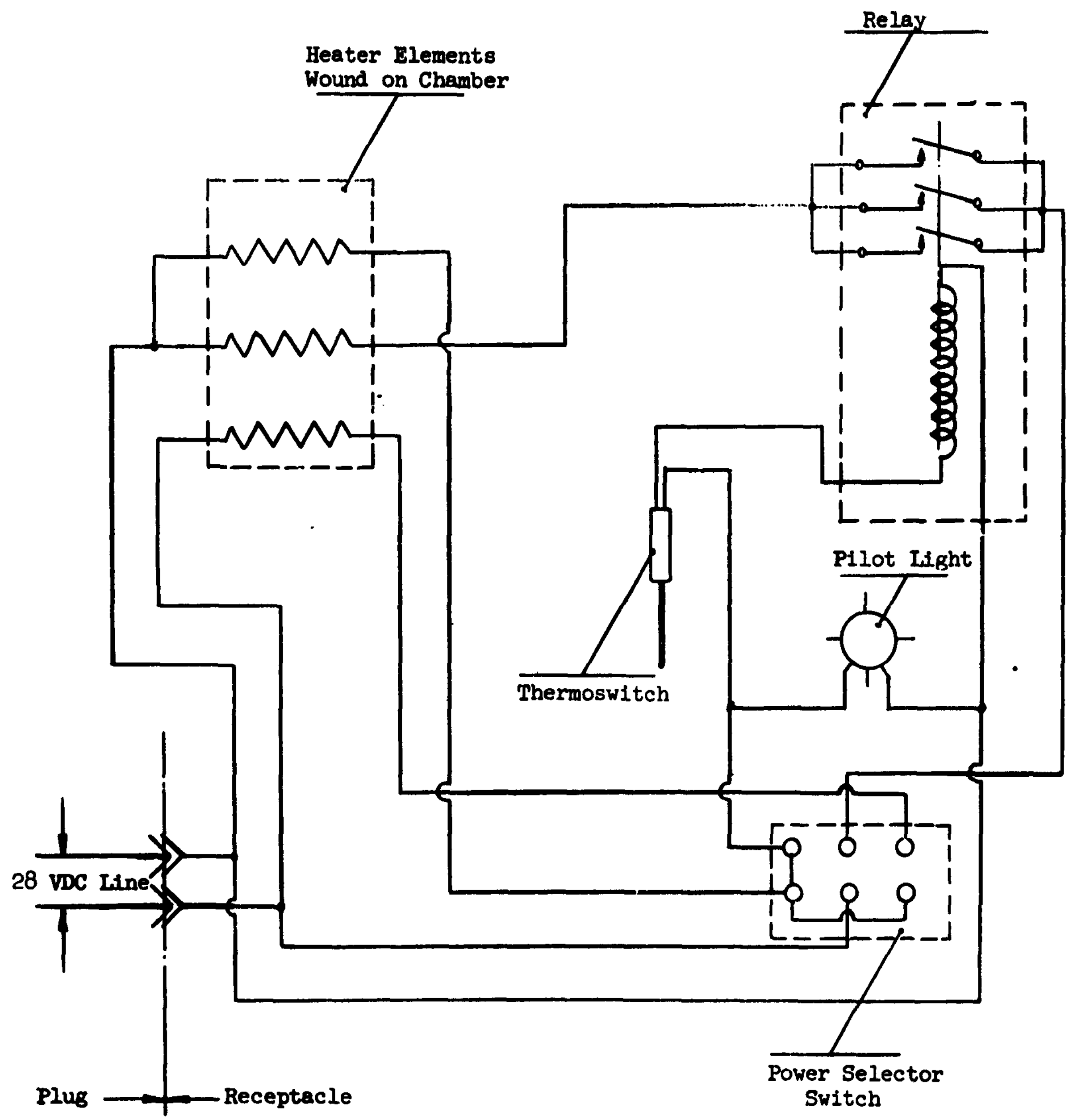

Figure 16 INCINERATOR WIRING DIAGRAM

SECTION 4

EVALUATION OF THE LABORATORY MODEL INCINERATOR

Several calibration tests and five performance tests were performed to evaluate the laboratory model incinerator.

Calibration Tests

During final assembly of the incinerator several tests were performed to check-out the system components. One of these tests was concerned with proof-testing of the resistance heaters. It was demonstrated that the heaters could be operated on 110-volt power without short circuiting.

The system leakage was evaluated by means of a 0.1 cubic-foot wet test meter connected to the outlet of a 2 cubic feet per minute vacuum pump. With the incinerator heated to 1000°F and evacuated to 4 millimeters of Mercury (absolute) the wet test meter did not register any leakage over a 1.5-hour period.

During the sterilization portion of the first full incineration cycle attempted, it was necessary to open the exhaust valve to prevent excessive internal pressure. The tube size downstream of the relief valve was too small to carry the volume of exhaust gas without a large pressure gradient in the line. Equilibrium could not be achieved without higher valve inlet pressure or higher internal incinerator pressure, which would be excessive. The condition was corrected by plumbing the relief valve back side directly into the 1-inch diameter main vacuum line. Thus more than adequate flow area was afforded. Thereafter the relief valve functioned as planned.

Evaluation Tests

Resistance Heating

The unit was set up for evaluation testing as shown in Figure 17. Photographs of a typical load before and after processing is shown in Figure 18 and results of the various tests are shown in Table 14. The results show that input energy is slightly higher than that predicted earlier in the program owing to the substitution of less effective insulation material for that originally planned. Original calculations were based upon the use of Johns-Manville "Min-K" with a thermal conductivity of 0.019 Btu per foot-hour-°F but its unavailability forced the substitution of "Thermacil", a fibrous calcium silicate insulation with a thermal conductivity of 0.044 Btu per foot-hour-°F made by Baldwin-Ehret-Hill. The 236 per cent increase in conductivity is not realized in increased power consumption, because the insulation blanket was made with increased depth - at the expense of volume and weight, to hold the outer skin temperatures below 120°F with normal cabin temperatures.

Further analysis of the test results show oxygen consumption is approximately one-fifth that originally predicted. An even distribution of oxygen by the oxygen manifold and injector, which were described above, allows that reduction by avoiding a tunnel cut through the waste by a concentrated O_2 stream from an inlet hole to an outlet hole. More exposure of the oxygen to the waste affords a better opportunity for reaction. Measurements taken with a gas chromatograph show less than 7 per cent O_2 in the exhaust gas at the prescribed oxygen flow rate.

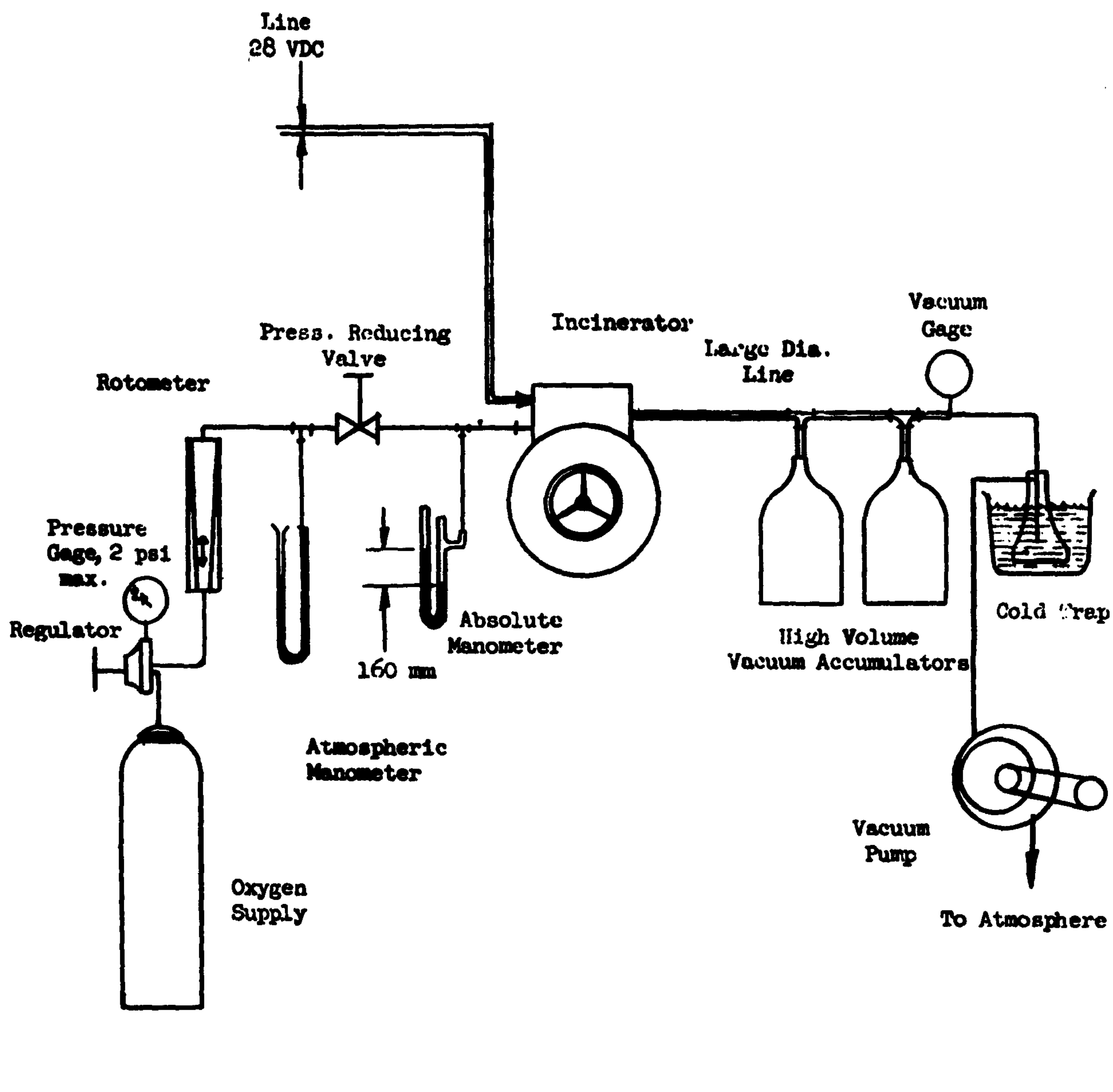

Figure 17 SCHEMATIC OF TEST APPARATUS

BEFORE PROCESSING

1. Sponges
2. Polyethylene
3. Paper
4. Food Waste (Beef Stew)
5. Lucite
6. Feces in Polyethylene bags with Rubberband

(NOTE: 12" scale)

AFTER PROCESSING

Dry, Gray Powder

(NOTE: 6" Scale)

Figure 18 INCINERATOR LOAD NO. 3

TABLE 7 INCINERATION TESTS RUN AT MRD

Test Run Number	Material Incinerated	Total Wt. Grams	Total Oxygen Consumed, lb	Input kw-hr	Test Duration hrs	Residue	
						wt., gms	Appearance
1	Wet Paper	309.7	0.04	0.82	2-1/2	0.7	Dry, White Powder
2	Full Load(1)	1190	0.453	2.54	7-3/4	49.2	Charred(3) Black Cinder
3	Full Load	916.1	0.495	3.84	13-3/4	21.9	Dry, Gray Powder
4A	Full Load	917.2	0.480	3.5(2)	11	----	Charred but in Tact(3)
4B	Residue from 4A	-----	0.21	1.5	5-1/4	12.9	Dry, Gray Powder
5	Full Load	1064	0.474	3.05(2)	13-1/4	14.1	Dry, Gray Powder

NOTES: (1) Full Load consists of Paper, Polyethylene, Food Waste, Sponges, Lucite, Feces and Rubberbands.

(2) Includes Solar Input and Extra Electrical Input to Overcome Losses Through Absorbing Surface.

(3) Incomplete Combustion

The first full load incinerator test, designated run number 2, was terminated after 7-3/4 hours. The residue was about 50 grams of charred, black cinder (evidence of incomplete combustion). The 20 to 1 weight reduction of the sample, however, indicated that the total oxygen consumed was near the required quantity and that more time at temperature would reduce the residue further. In test number 3 the incineration time was extended to 13-3/4 hours with the total oxygen input approximately the same. The residue was a very dry, gray powder which compacted much the same as talcum. No odor of any kind was sensed from any of the residue.

The effect of reduced temperature was observed in test run number 4A, when solar heating was applied to the incineration chamber. The residue was thoroughly blackened but intact after that 11-hour run. The residue was left in the chamber and reduced to dry, gray powder in run 4B. The duration of run 4B was 5-1/4 hours which is approximately twenty per cent longer than the time by which run 3 exceeded run 2. That adjustment was made because the charred residue from run 4A was intact, while that left after run 2 had progressed further toward complete combustion.

Run number 5 was made to demonstrate a complete cycle incineration to the project monitors.

Solar Heating

Test run number 4A was made with partial simulated solar heating. Simulated solar radiation was supplied by a Strong Solar Simulator at an intensity level of 1.38 times the solar constant, or 93 watts on the exposed area of .545 ft^2. The hot surface, however lost energy at a higher rate than that absorbed at temperatures above 510°F. More concentrated radiation is necessary to facilitate the practical application of solar heating. Even if perfect black body absorptivity could be achieved, the small improvement over the present value of energy absorbed would be inadequate. The other alternative of increasing incident radiation shows greater promise. The required energy absorption rate, with the absorbing surface exposed, is at least 510 watts*, which is nearly 8 times the solar constant. Thus, if the same absorbing surface size was retained, an 80 per cent efficient concentrator approximately 3-ft diameter normal to the sun's rays would be required.

Due to the low temperature experienced in that test, incineration was incomplete. The insulation was replaced, the entire system allowed to cool overnight, and incineration was carried to completion the next day by resistance heating. That run is designated 4B in the table.

As was anticipated, the process was observed to be insensitive to such an intermittent schedule of operation.

* The quantity is calculated by extrapolating heat loss along a straight line from 760°F to operating temperature. The actual heat required is greater because some of the losses are by radiation which are proportional to the 4th power of temperature difference.

Conclusions

The evaluation test results show that the flight prototype waste incinerator does reduce the daily wastes of three men to a dry powder, which could be vented overboard from an aerospace vehicle. The total process cycle requires 12 hours and approximately 0.5 pounds of oxygen with an incinerator temperature of about 1000°F. The total electrical energy demand for this period is less than 4 kilowatt-hours.

SECTION 5

LIST OF REFERENCES

1. Zeff, J. D. (et al), Storage Unit for Waste Materials, ASD Technical Report 61-200, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, June 1961.

2. Zeff, J. D. (et al), Study and Experimental Model of an Internal Environmental Simulator for Space Crew, Study Phase Report, AMF Report MR 1122-15, Contract N61339-786, Mechanics Research Division, Niles, Illinois, July 1960.

3. Lewis, W. K. and A. H. Radasch, Industrial Stoichiometry, First Edition, McGraw-Hill, New York, 1926.

4. Modern Plastics, Encyclopedia Issue for 1961, Vol. 38, Number 1A, New York, September 1960.

5. Norell, M. W., (et al), Restaurant Waste Disposal Unit, Phase 1 - Background Study, AMF Proprietary Report MR 8571, Mechanics Research Division, Niles, Illinois, December 1959.

6. Celanese Fortiflex Molding Compounds, Celanese Corporation of America, Plastics Division, 744 Broad Street, Newark 2, New Jersey, No date listed.

7. Perry, John H., Chemical Engineer's Handbook, Third Edition, McGraw-Hill, New York, 1950.

8. Hawk, D. B., (et al), Practical Physiological Chemistry, p. 446, McGraw-Hill, New York, 1954.

Aerospace Medical Division
6570th Aerospace Medical Research
Laboratories, Wright-Patterson AFB, Ohio
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is 700° F. (c) Incineration using pure oxygen at 160 mm Hg absolute generates 100 watts after ignition has been attained. (d) Thermal decomposition of the wastes requires a continuous input of 390 watts for 12 hours. Based upon the power requirements and a mass penalty of 0.15 pound/watt, incineration with pure oxygen was found to be best waste-disposal technique for a 3-man, 14-day mission. In the second phase, the laboratory model was designed, fabricated, and tested. The complete system weighed 81 lbs and occupied 3.1 cubic feet. It was determined experimentally that a complete incineration cycle requires 2.6 kw-hr of electrical energy and 1/2 lb of oxygen, over a 12-hour period.

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